Study of the NMR apparatus linearity

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1 Introduction

In this document, we report on the systematic study of the size of the signal versus the RF power. Understanding such performance is important because the Thermal-Equilibrium (TE) calibration for the polarimetry is done at high power, typically -5 or -10 dBm, while the measurement of a highly polarized HD cell is done typically around -45dBm. The correction for the different amount of power is done assuming a linear dependence of the system with the RF power. In addition, the size of signal should change by a factor 10^4 between TE signal and a highly polarized target signal, possibly producing non-linearities from e.g. saturations. This study checks the response of the system with the output signal size and input RF power value.

An initial study has been reported in [1]. For convenience, we include these data in this report.

2 List of runs

All the runs where taken with the White cable. The runs of interest are coded with color, with runs from a same period and conditions having the same color.

The CH_2 runs were done on target #3 will all Al. cooling wires.

HD#1 was a target condensed on July 22nd 2011 and then evaporated.

HD#2 was condensed on August 12th 2011 and then evaporated.

HD#19 was condensed on March 19th 2011 for production run (bottom target in the DF). It was eventually used for spin operation studies.

Run #	T^o	target	cycles	B-span	B-center	T_{up}	RF $\lambda/2$ res. freq. & phase	RF $\lambda/2$ res. amp	Ex. Gas	RF (dBm)	comments
175996735	4.275K	CH_2	330	300G	2825	16s	$12311/142^o$	(3.727×10^{-4}V)	yes	-5	run originally taken for $T_{up,down}$ study RF scan from 4 days ago
176029323	4.28K	CH_2	326	150G	2865	16s	$12311/142^o$	As above	yes	-5	run originally taken for B span study
177177374	4.27K	CH_2	vary	330G	2840	16s	$12317/140^o$	3.667×10^{-4}V	yes	0 to -25	T_1 of 8 min
187741329	4.275K	HD#1	20	150	2830	16s	$12289/143^o$	6.26×10^{-4}V	yes	0	H run
187750169	~4.28K	HD#1	380	150	2830	16s	$12289/143^o$	As above	yes	-10	H run
187978374	4.276K	HD#1	525	150	2830	16s	$12289/143^o$	As above	yes	-25	H run
188032997	4.273K	HD#1	22	150	2830	16s	$12289/143^o$	As above	yes	-2	H run
188035286	4.273K	HD#1	25	150	2830	16s	$12289/143^o$	As above	yes	0	H run
188047003	4.3K	HD#1	vary	150	2830	16s	$12289/143^o$	As above	yes	-1 to -20	H run
188131733	4.27K	HD#1	vary	150	18650	16s	12289/143	As above	yes	0 to -25	D run
189543611	4.276K	HD#2	vary	150	2830	16s	$12286/143^o$	5.986×10^{-4}V	yes	-15 to-35	H Run
189710767	4.27K	HD#2	392	150	2830	16s	$12286/143^o$	5.986×10^{-4}V or 3.112×10^{-4}V	yes	-40	H run RF res. scan done after the run.
189774319	4.27K	HD#2	186	150	2830	16s	$12286/143^o$	3.115×10^{-4}V	yes	-40	H run
189859117	4.27K	HD#2	vary	150	2830	16s	$12286/143^o$	2.72×10^{-4}V	yes	-15 & -45	H run freq & phase is off (should have been 12307/136
190200064	4.8K	HD#2	vary	150	2830	16s	$12327/133^o$	2.101×10^{-4}V	no	-5 to -20	last condition done at RF $\lambda/2$ res. freq. & phase $12286/143^o$
191942328	3.17K	HD#19	3	300	2903	31s	$12330/128^o$	1.293×10^{-5}V	no	-40	frozen spin mode
191943060	3.18K	HD#19	1	300	2903	31s	$12330/128^o$	as above	no	-50 & -55	frozen spin mode
191943528	3.18K	HD#19	1	300	2903	31s	$12330/128^o$	as above	no	-25, -30, -35 and -60	frozen spin mode
192377846	2.0K	HD#19	vary	300	2903	31s	$12330/128^o$	1.295×10^{-5}V	yes	-29, -32, -38, -42, -45 and -52	frozen spin mode
192380580	2.0K	HD#19	vary	300	2903	31s	$12330/128^o$	1.295×10^{-5}V	yes	-58, -40,	frozen spin mode

3 Analysis of Runs PD177177374, PD175996735 and PD176029323 (CH_2 run)

This section is a copy of the analysis reported in [1]

3.1 Run details

The run was done on CH_2 target #3 with aluminum cooling wires set in the cooling holes, but without any aluminum cap. It was latter found out that, although target #3 was made of the same material as the other CH_2 targets (#1, #2 and INFN targets), it displays a measurable T_1, while the others do not [2]. The reason for this difference is unknown. The consequence for our study is that we have to be sure to be at thermal equilibrium when we measure the effects of the

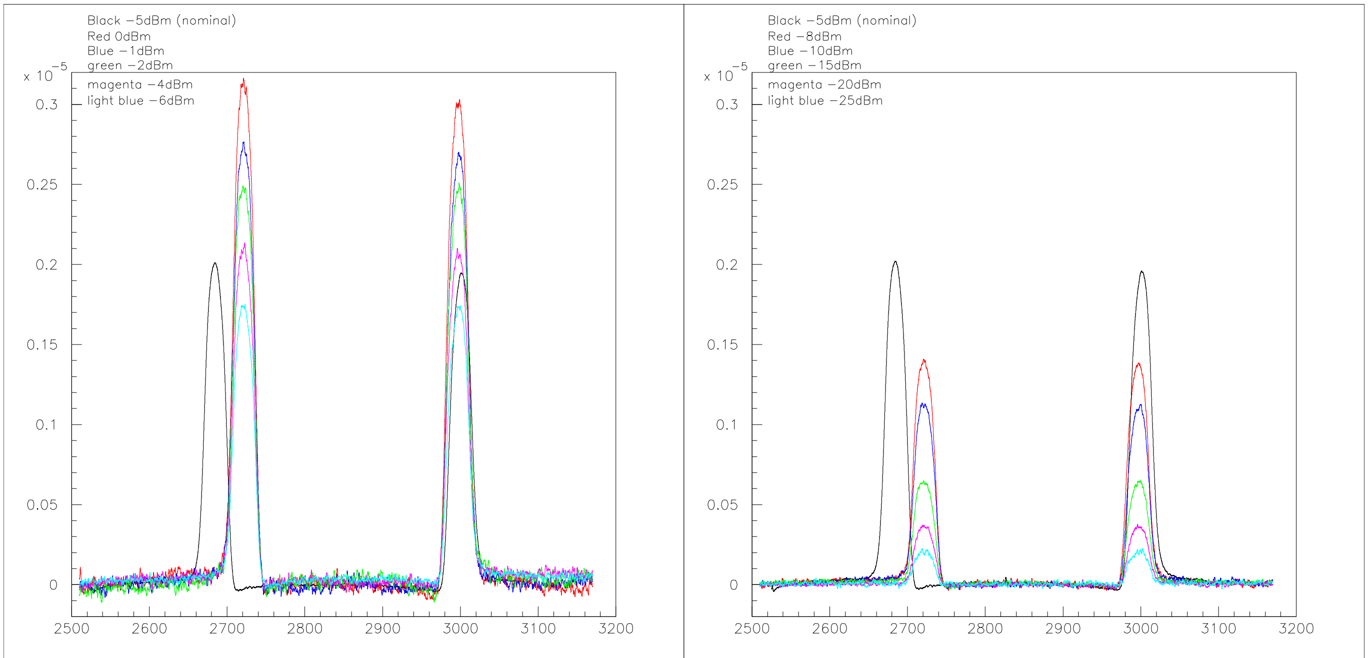


Figure 1:
Variation with RF power of the NMR peak areas. The NMR peaks for the nominal value for RF power (black line) are not aligned with the other peaks because a different B-field span vs used. On the left panel, results for runs at 0.-1, -2, 4 and -6dBm together with nominal run at -5dBm (run PD175996735). On the right panel, results for runs at -8,-10.-15, -20 and 25 dBm together with nominal run at -5dBm (run PD176029323).

RF power. This may entail dropping the first few sweeps at the beginning of runs and monitor the stability of the NMR signal amplitude vs time for a given running condition. The constant parameters for the runs are given in section 2. The changing parameters and the NMR signal strength (integrated over 50 Gauss) are:

index	RF power	cycles	area(down/up)$\times 10^6$	Width(d/u) (G)	Height(d/u)$\times 10^6$	area jitter (d/u)$\times 10^6$	Notes
1	0dBm	20	88.741/86.647	29/29	3.162/3.038	4.06/4.56	Apparent RF losses
2	-1dBm	20	78.309/76.132	29/29	2.750/2.696	2.65/2.70	
3	-2dBm	20	70.843/70.555	29/29	2.486/2.493	2.87/2.14	
4	-4dBm	40	58.425/57.982	29/29	2.120/2.081	1.98/2.35	
5	-6dBm	60	48.347/ 48.324	29/29	1.747/1.747	2.02/1.96	
6	-8dBm	80	39.335/39.608	29/29	1.409/1.391	1.56/1.30	
7	-10dBm	100	31.849/ 31.374	29/29	1.138/1.127	1.54/1.36	
8	-15dBm	150	18.180/18.353	29/29	0.645/0.652	1.28/1.36	
9	-20dBm	200	10.338/ 10.225	29/29	0.373/0.370	1.36/1.27	
10	-25dBm	79	5.803/5.774	29/29	0.227/0.219	1.26/1.34	

These data can be compared to the data taken at the nominal RF power of -5dBm from e.g. runs PD175996735 and PD176029323:

Run PD175996735:

Int. range	Area (down)	Width (down)	height (down)	Area (up)	Width (up)	height (up)
79 Gauss	5.73×10^{-5}	29.0 Gauss	2.03×10^{-6}	5.66×10^{-5}	29.2 Gauss	1.97×10^{-6}

Run PD176029323:

Int. range	Area (down)	Width (down)	height (down)	Area (up)	Width (up)	height (up)
80 Gauss	5.72×10^{-5}	29.4 Gauss	2.01×10^{-6}	5.62×10^{-5}	29.4 Gauss	1.97×10^{-6}

The NMR peaks averaged over all sweeps are shown for different RF powers in Fig. 1.

3.2 Time dependence of the signals

The time dependence of the peak areas are given in Fig. 2. There is a clear loss of polarization for the largest RF power (0 dBm). This effect is visible because of the larger T_1 of CH_2 cell #3 [1]. It will presumably not be visible for the other CH_2 cell that have shorter T_1 and much more visible with the long T_1 HD cells.

3.3 NMR signal strength versus RF power

The dependence of the NMR signal area in function of RF power is shown on Fig. 3. The signal follow a pure exponential up to about -10 dBm. At higher powers, we deviate from the exponential, presumably because of RF polarization loss. This deviation should be function of T_1 (if it is long enough) and of the number of sweep. For CH_2 target #3, $T_1 = 8.1$ min. On Fig. 3, the signals were fitted with the exponential form $1.0 \times 10^{(x/20)}$ where x is the RF power in dBm. The ratios between the measurements and the fit are shown on the bottom of the figure. Also shown on Fig. 3 are results at -5 dBm from runs PD175996735 and PD176029323 (square symbols). These results do not line-up with the data of run PD177177374. This is because they were obtain with a different target (CH_2 #1) with a much shorter T_1 (too short to be measured by our experimental apparatus). No RF loss are visible for these runs. This confirms that the RF loss seen are due to the longer T_1 of target CH_2 #3.

Note, although we obtain a ~linear relation in the log plot, it does not have the expected coefficient: the power should be $P \propto 10^{(dbm/10)}$, while we found it to be $10^{(dbm/20)}$. why??

4 Analysis of runs PD17750169 to 188047003 (H run with exchange gas)

4.1 Run details

The runs were done on a HD cell condensed on July 22$^{\text{nd}}$ 2011 with relatively high impurity HD gas. Presumably, it has a very small T_1. The constant parameters for the runs are given in section 2. The changing parameters and the NMR signal strength (integrated over 30 Gauss) are:

run-index	RF power	cycles	area(down/up)$\times 10^6$	PD T^o	Notes
187741329	0dBm	20	50.617/50.009	4.275K	peaks offset (reason unknown)
187750169	-10dBm	380	15.467/15.466	~4.28K	
187978374	-25dBm	525	2.746/2.694	4.276K	
188032997	-2dBm	22	38.870/38.727	4.273K	
188035286	-0dBm	25	49.330/48.944	4.273K	
188047003-1	-1dBm	20	43.390/43.461	4.274K	
188047003-2	-4dBm	40	30.863/30.855	4.272K	
188047003-3	-5dBm	50	27.379/27.365	4.270K	
188047003-4	-6dBm	60	24.604/24.572	4.269K	
188047003-5	-8dBm	80	19.262/19.272	4.269K	
188047003-6	-12dBm	100	12.143/12.139	4.270K	
188047003-7	-15dBm	130	8.608/8.626	4.271K	
188047003-8	-20dBm	152	4.832/4.800	4.272K	

The areas in the tables are not corrected yet for the PD temperature difference. The NMR peaks averaged over all sweeps are shown for different RF powers in Fig. 4.

4.2 Time dependence of the signals and uncertainty.

We checked the time dependence for the runs. There is no visible time dependence of the peak areas, see Fig. 5. This was expected due to the short T_1 of the cell. The jitter of the signal is taken as the uncertainty on the measurement.

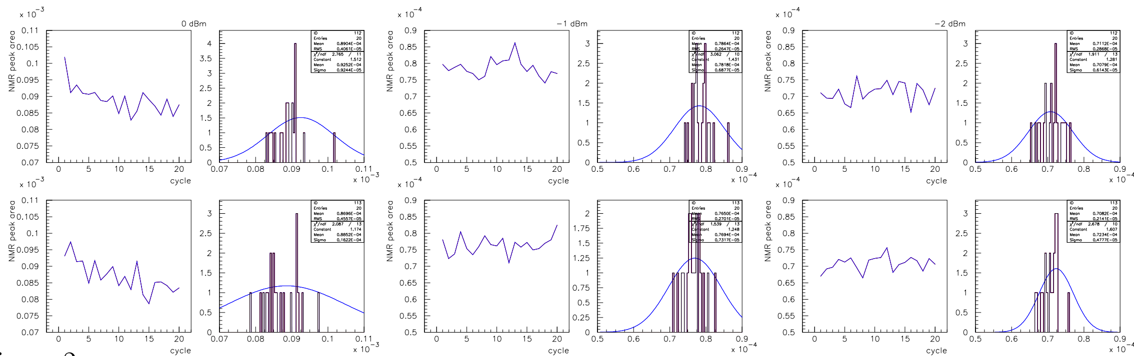
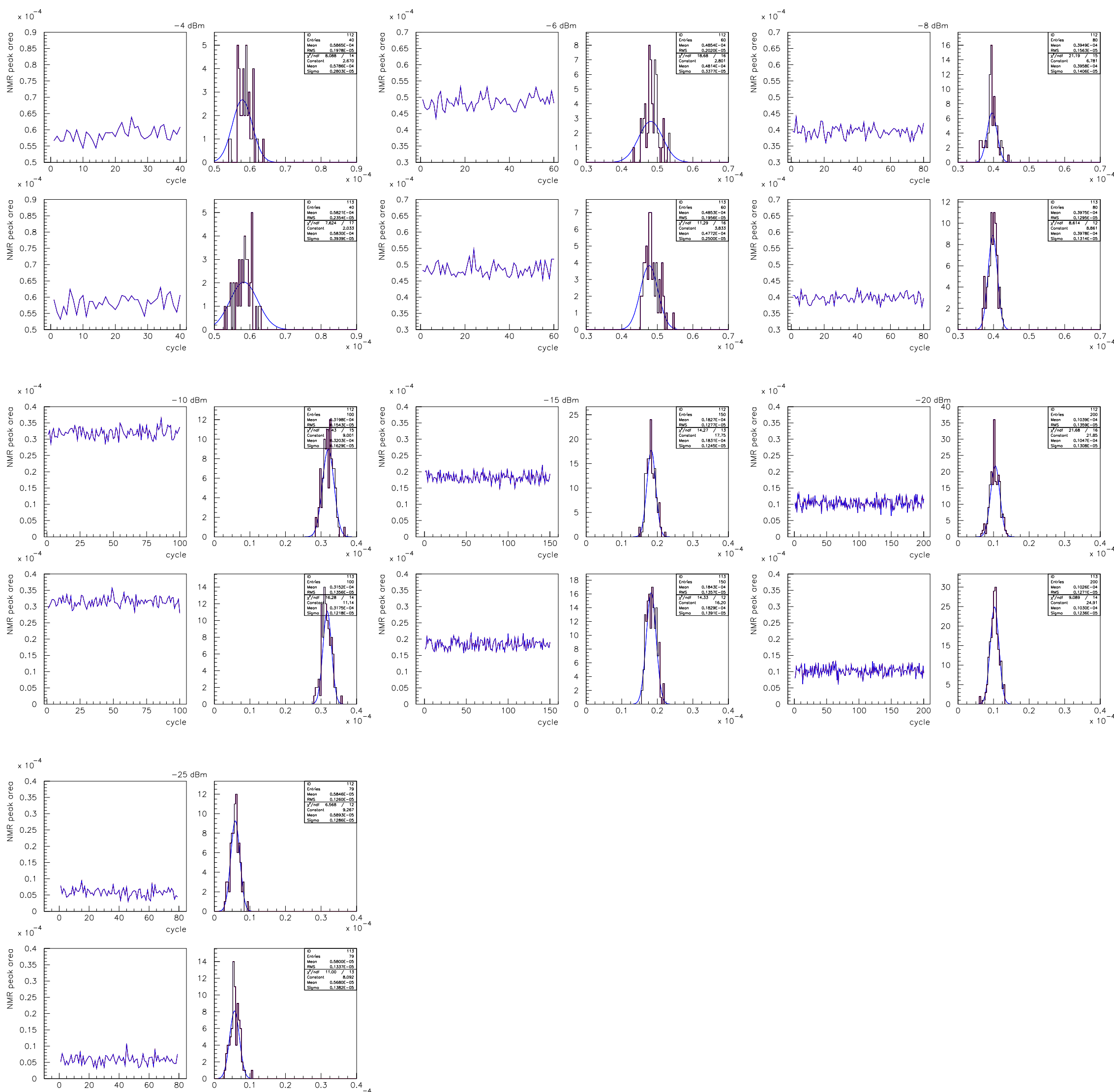


Figure 2:



Peak area jitter. Each panel corresponds to a different RF power. On the left of one panel: Area of the NMR peak vs sweep number (cycle) for the NMR peak for the sweeps done for H. The top plot is for the down sweeps and the bottom plot is for the up sweeps. On the right of one panel: corresponding distributions together with their Gaussian fits.

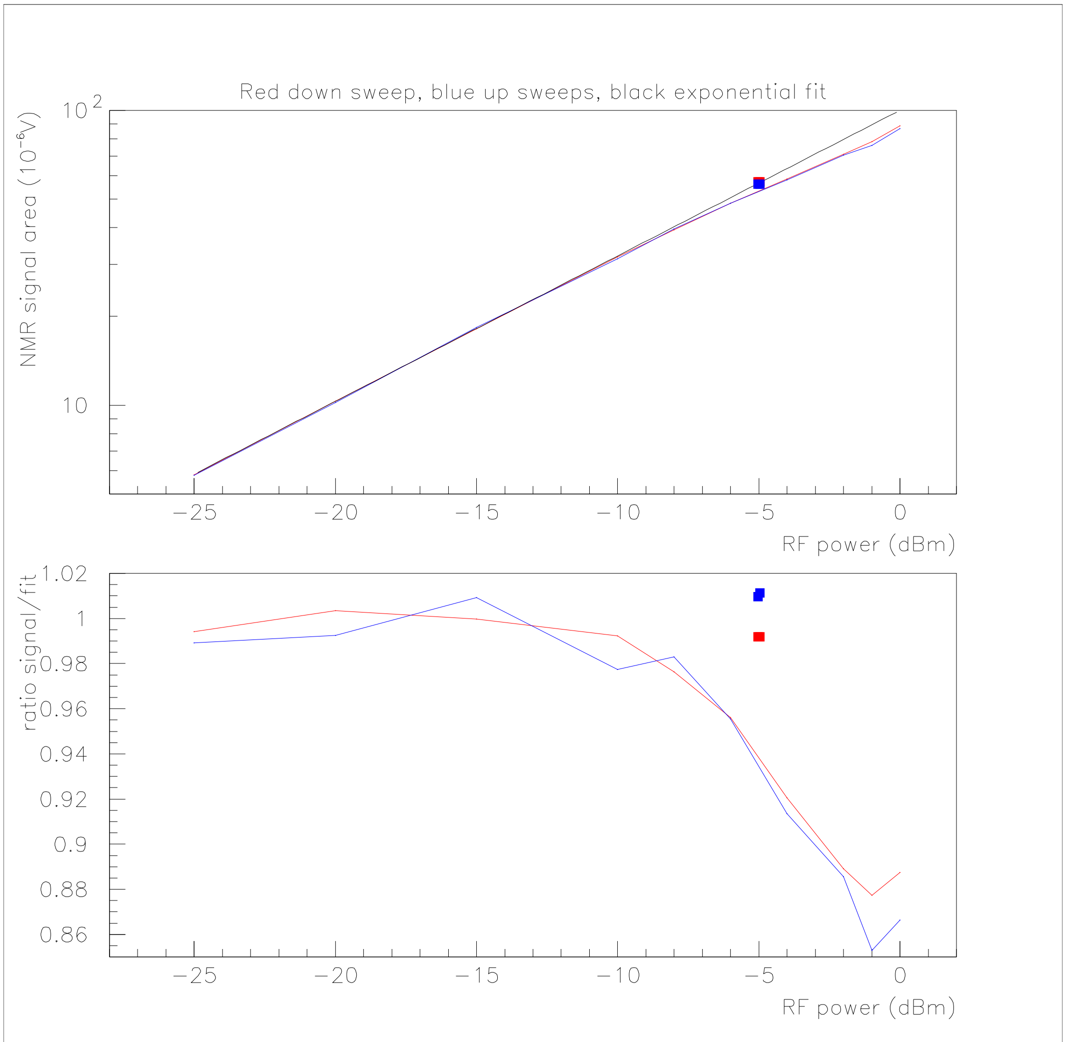


Figure 3:

Top: The red (blue) line gives the dependence of the down (up) NMR signal area in function of RF power for CH_2 target #3 (T_1 = 8.1 min, see [2]). The squares are results for the -5dBm standard run using CH_2 target #1 (very short T_1). Bottom: ratios of the measured area over the exponential fit in function of the RF power.

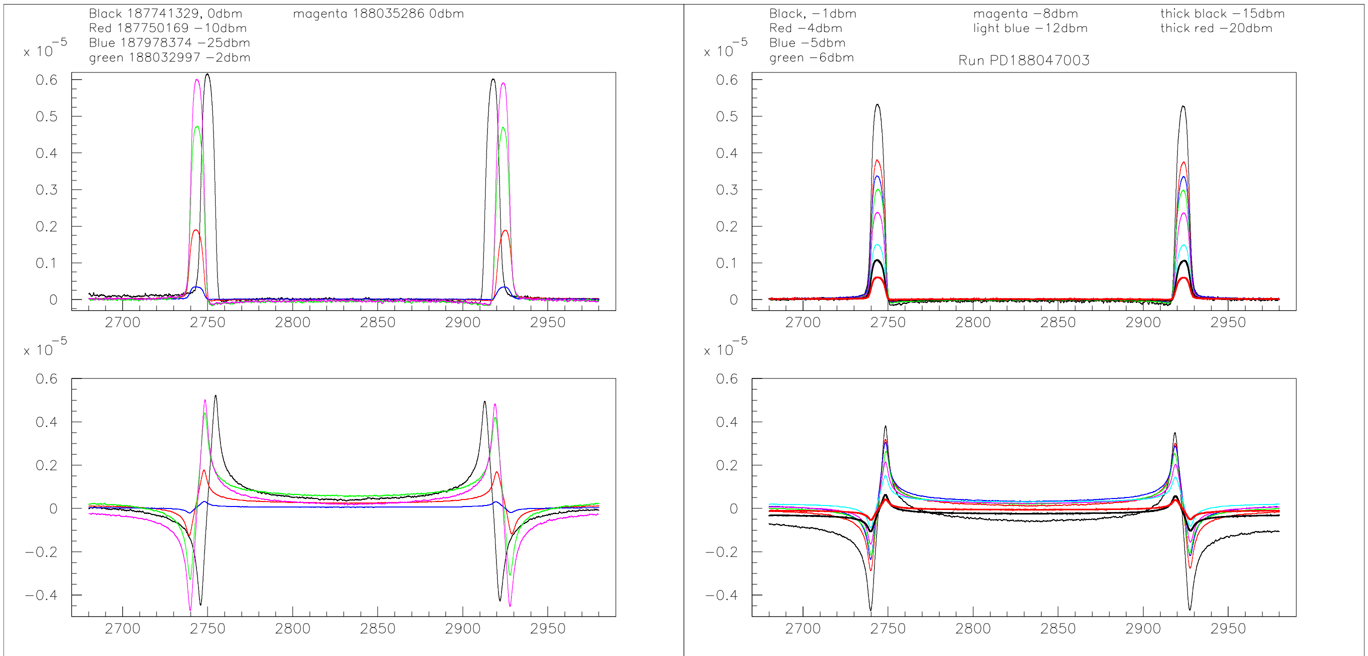


Figure 4:
Variation with RF power of the NMR peak areas. The slight difference of PD temperature has been corrected for.

4.3 NMR signal strength versus RF power

The dependence of the NMR signal area in function of RF power is shown on Fig. 6. The signal follows a pure exponential. On Fig. 6, the signals were fitted with the exponential form $48.5 \times 10^{(x/20)}$ where x is the RF power in dBm. The ratios between the measurements and the fit are shown on the bottom of the figure.

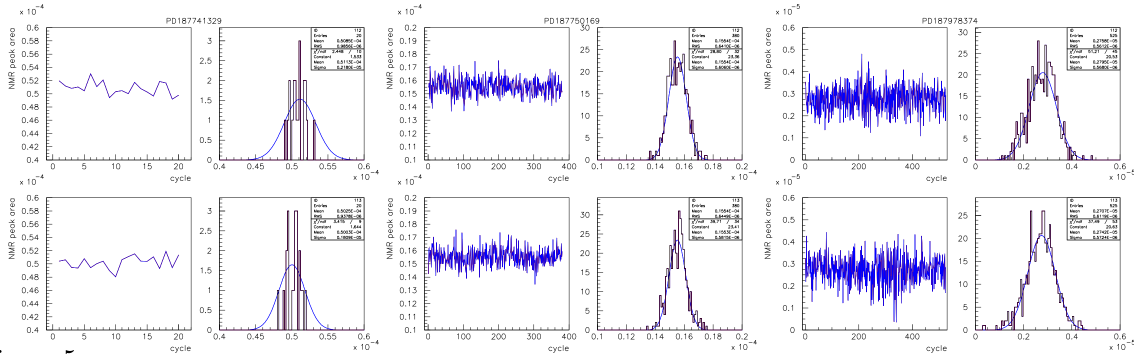
5 Analysis of run PD188131733 (Deuteron run)

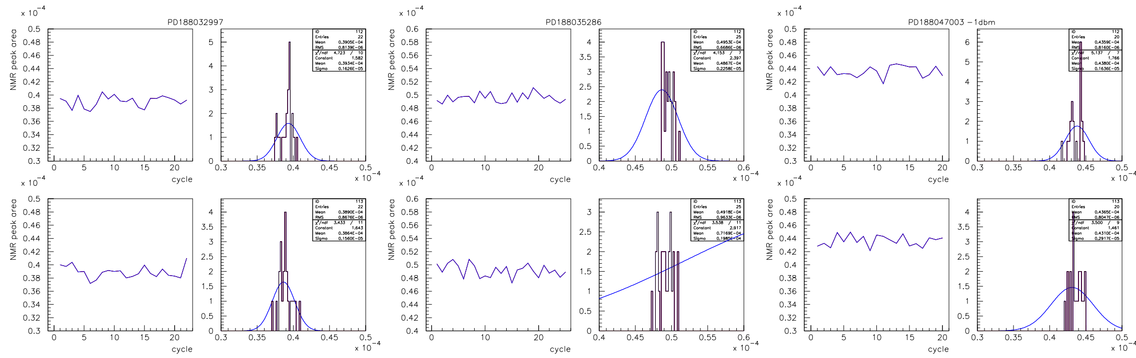
5.1 Run details

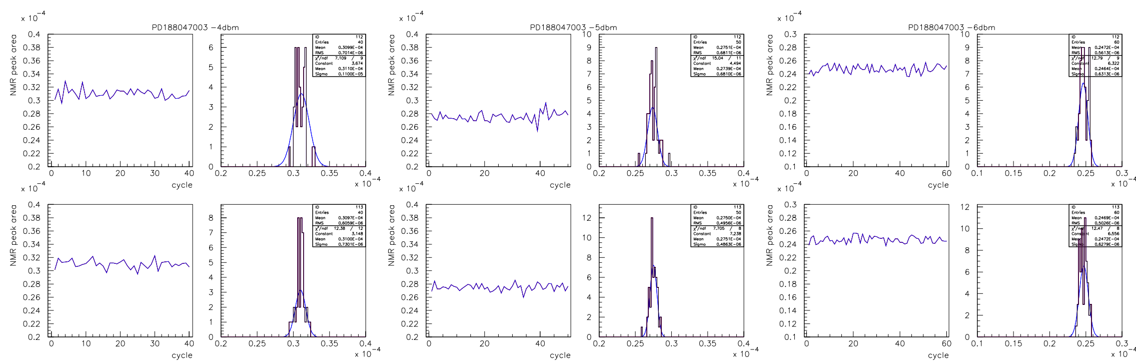
The run was done on a HD cell condensed on July 22$^{\text{nd}}$ 2011 with high impurity exchange gas. The deuteron NMR was measured. The constant parameters for run PD188131733 are given in section 2. The changing parameters and the NMR signal strength (integrated over 40 Gauss) are:

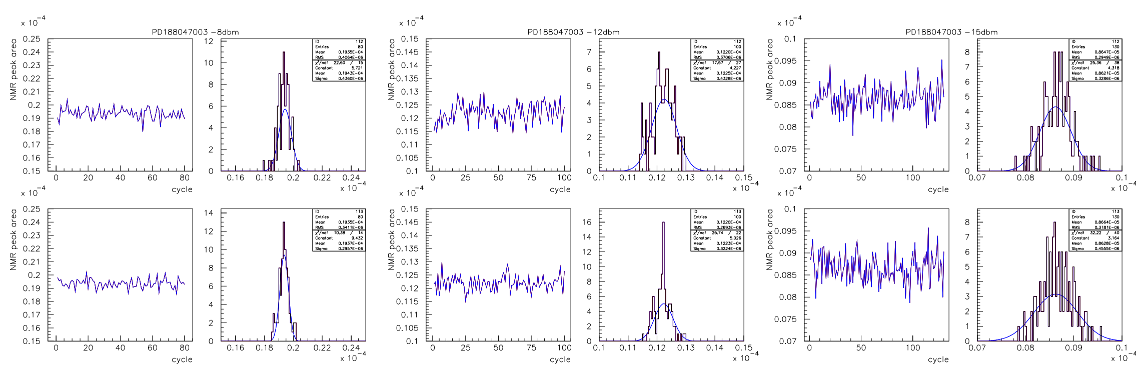
run-index	RF power	cycles	area(down/up)$\times 10^6$	PD T^o	Notes
188131733-1	-0dBm	20	20.486/20.525	4.266K	
188131733-2	-1dBm	20	17.845/17.647	4.266K	
188131733-3	-2dBm	20	16.369/16.034	4.267K	
188131733-4	-4dBm	40	12.647/12.503	4.266K	
188131733-5	-5dBm	50	11.251/11.343	4.265K	
188131733-6	-6dBm	60	10.040/9.994	4.265K	
188131733-7	-8dBm	80	8.136/7.897	4.266K	
188131733-8	-10dBm	500	6.325/6.300	4.267K	
188131733-9	-12dBm	55	4.942/5.064	4.268K	

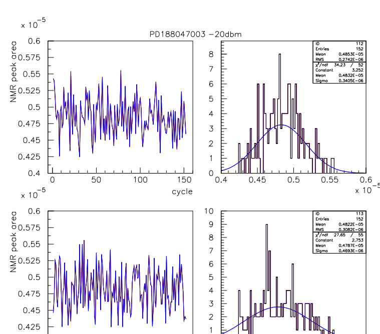
The areas in the tables are not corrected yet for the PD temperature difference. The NMR peaks averaged over all sweeps are shown for different RF powers in Fig. 7.


PD187741329
PD187750169
PD187978374
NMR peak area
cycle
Figure 5:


PD188032997
PD188035286
PD188047003 −1dbm
NMR peak area
cycle


PD188047003 −4dbm
PD188047003 −5dbm
PD188047003 −6dbm
NMR peak area
cycle


PD188047003 −8dbm
PD188047003 −12dbm
PD188047003 −15dbm
NMR peak area
cycle


PD188047003 −20dbm
NMR peak area
cycle

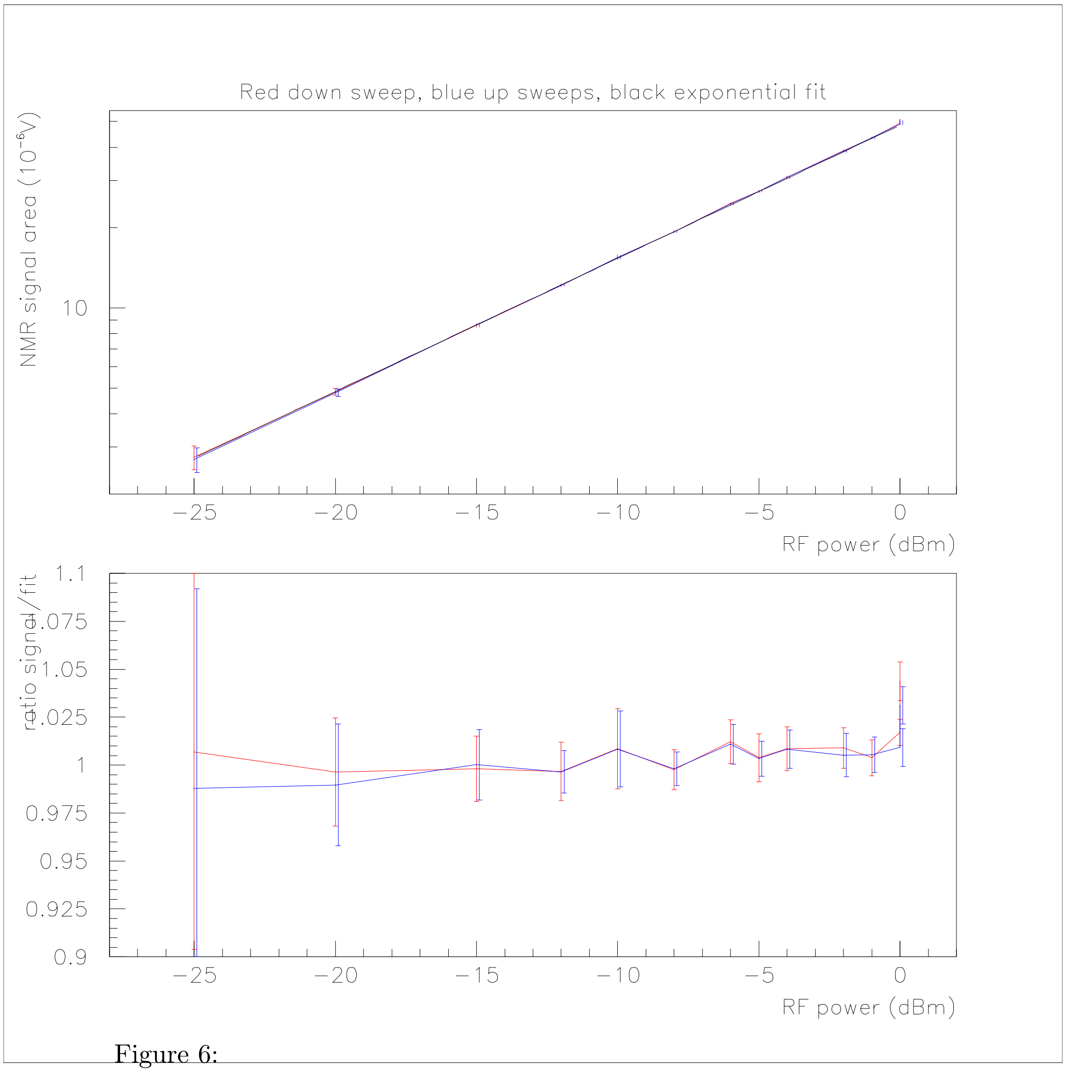


Figure 6:

Top: The red (blue) line gives the dependence of the down (up) NMR signal area in function of RF power. Bottom: ratio of the measured area over the exponential fit in function of the RF power. (The 0dBm run not in line with the fit is run 187741329, which displays a shift in position. So this discrepancy may be ignored.)

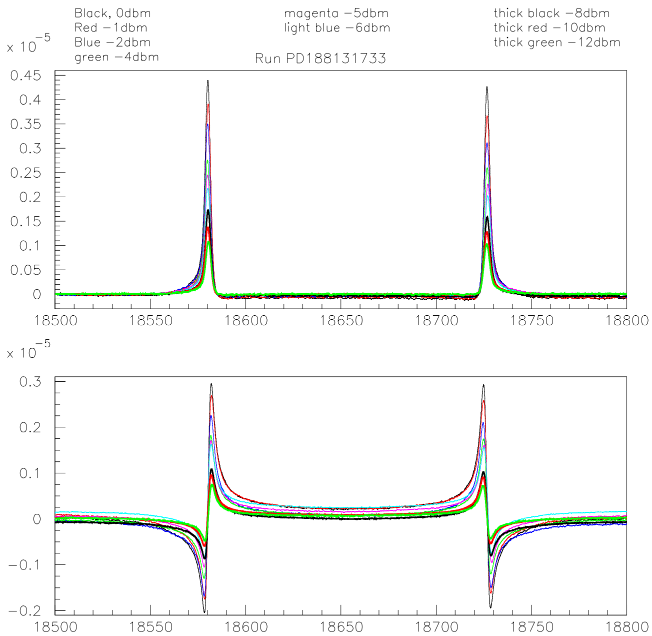


Figure 7:
Variation with RF power of the NMR deuteron peak areas.

5.2 Time dependence of the signals and uncertainty.

We checked the time dependence for the runs. There is no visible time dependence of the peak areas, see Fig. 8. This was expected due to the short T_1 of the cell. The jitter of the signal is taken as the uncertainty on the measurement.

5.3 NMR signal strength versus RF power

The dependence of the NMR signal area in function of RF power is shown on Fig. 9. The signal follows a pure exponential. On Fig. 9, the signals were fitted with the exponential form $20. \times 10^{(x/20)}$ where x is the RF power in dBm. The ratios between the measurements and the fit are shown on the bottom of the figure.

6 Analysis of runs PD189543611 to 189859117 (H run with exchange gas)

6.1 Run details

The runs were done on a HD cell condensed on July 12$^{\text{th}}$ 2011 with relatively high impurity HD gas. Presumably, it has a very small T_1. The constant parameters for the runs are given in section 2. The changing parameters and the NMR signal strength (integrated over 40 Gauss) are:

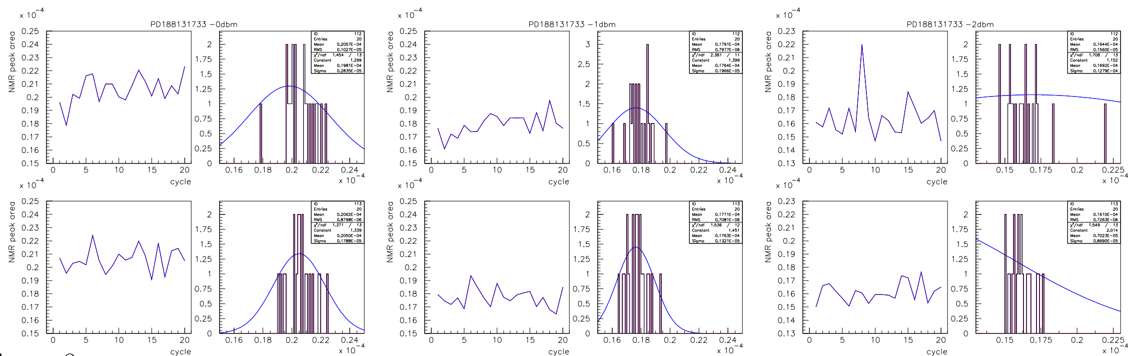
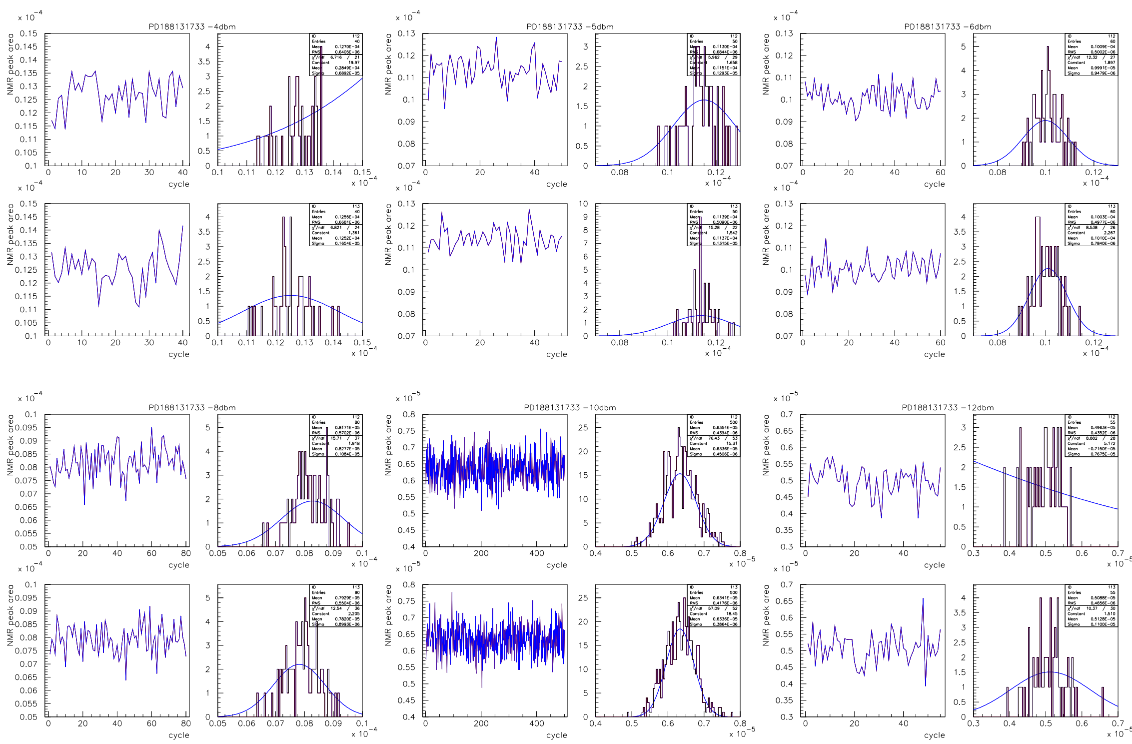


Figure 8:



Peak area jitter. Each panel corresponds to a different RF power. On the left of one panel: Area of the NMR peak vs sweep number (cycle) for the NMR peak for the sweeps done for H. The top plot is for the down sweeps and the bottom plot is for the up sweeps. On the right of one panel: corresponding distributions together with their Gaussian fits. The RMS of the distribution (jitter) is taken as the uncertainty on the measurement.

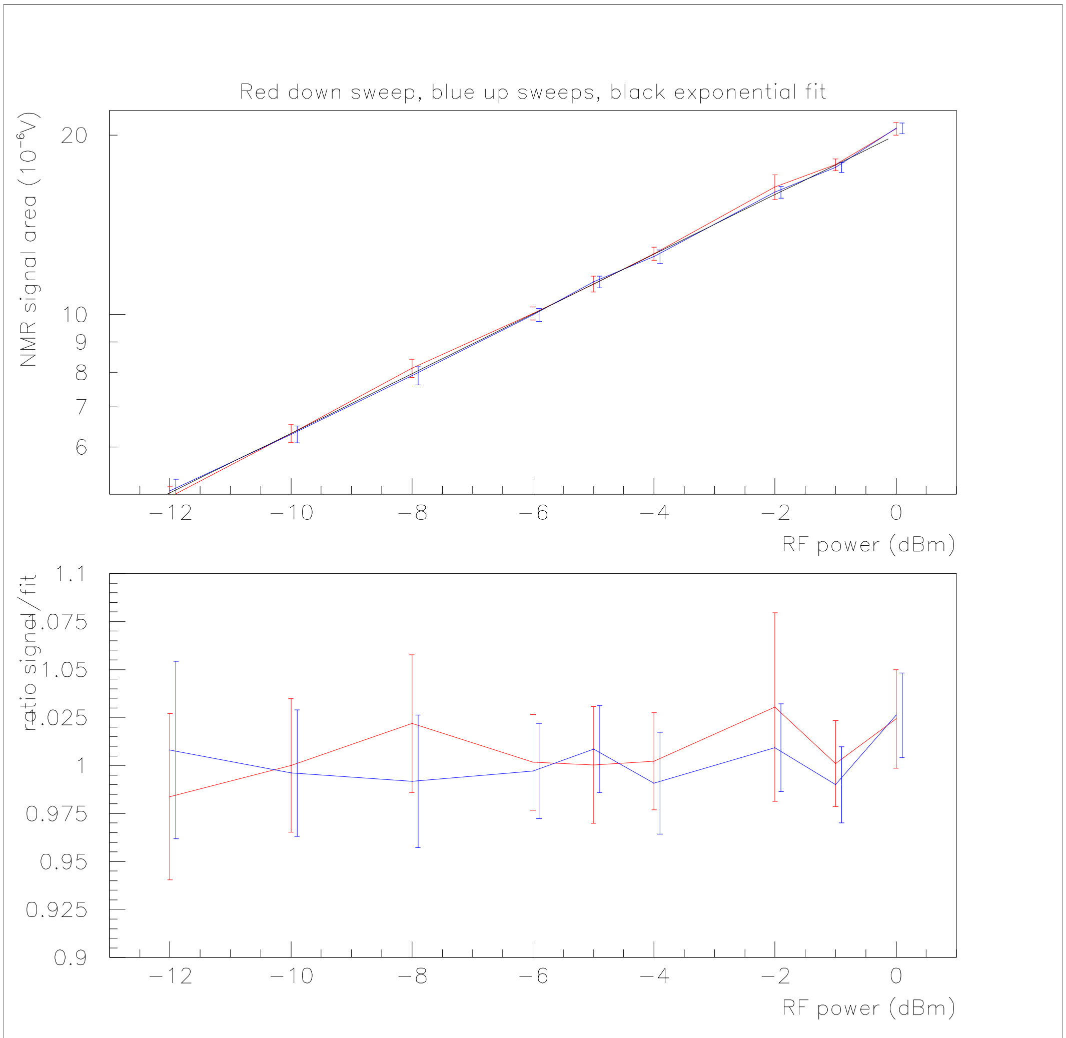


Figure 9:
Top: The red (blue) line gives the dependence of the down (up) deuteron NMR signal area in function of RF power. Bottom: ratio of the measured area over the exponential fit in function of the RF power.

run-index	RF power	cycles	area(down/up)$\times 10^6$	PD T^o	RF $\lambda/2$ res. amp	Notes
189543611-1	-15dBm	20	7.7371/7.799	4.276	5.986×10^{-4}V or 3.112×10^{-4}V	RF scan done 5 hours early. Next one done changed to amp=3.115×10^{-4}V
189543611-2	-20dBm	40	4.419/4.319	4.277	5.986×10^{-4}V or 3.112×10^{-4}V	
189543611-3	-25dBm	100	2.521/2.474	4.277	5.986×10^{-4}V or 3.112×10^{-4}V	
189543611-4	-30dBm	200	1.371/1.417	4.276	5.986×10^{-4}V or 3.112×10^{-4}V	
189543611-5	-35dBm	70	0.8175/0.8655	-	5.986×10^{-4}V or 3.112×10^{-4}V	no PD temp info. Assume 4.276K
189710767	-40dBm	391	0.4665/0.4960	-	5.986×10^{-4}V or 3.112×10^{-4}V	no PD temp info. Assume 4.265K
189774319	-40dBm	186	0.4833/0.4800	4.265K	3.115×10^{-4}V	
189859117-1	-15dBm	30	7.263/7.365	4.272K	2.72×10^{-4}V (done 6 min before run) or 1.75×10^{-4}V (done 5 h after run)	freq & phase are off (should have been 12307/136)
189859117-1	-45dBm	185	0.1523/0.1552	-	2.72×10^{-4}V or 1.75×10^{-4}V	freq & phase are off (should have been 12307/136)

The areas in the tables are not corrected for the slight PD temperature difference or the $\lambda/2$ resonance amplitudes. Run 189859117 is corrected for the phase mismatch. The NMR peaks averaged over all sweeps are shown for different RF powers in Fig. 10.

6.2 Time dependence of the signals and uncertainty.

We checked the time dependence for the runs, see Fig. 11. The means of the distribution should correspond to the average signal areas given in the table of section 6.1, which is not the case for one of the -40dBm run and the -35dBm and 45dBm runs. Consequently, their time dependence analysis and uncertainty estimate are unreliable. This may be due to the small size of the cycle per cycle NMR signal, which makes it hard to pick up from the noise.

6.3 NMR signal strength versus RF power

The dependence of the NMR signal area in function of RF power is shown on Fig. 12. There is a significant uncertainty on the results due to the varying $\lambda/2$ resonance amplitude. To make runs 189543611-5 and 189774319 compatible, the $\lambda/2$ resonance amplitude for run 189543611 must be 3.112×10^{-4}V (this is also supported when compared to the -15dBm run PD190200064-8). The $\lambda/2$ resonance amplitude for run 189859117-1 is expected to be 2.72×10^{-4}V, as it was measured a few minutes before the starts of the run. From the time dependence of the run, there is no indication of change. The time-dependence of run 189859117-2 is not reliable. The value 2.72×10^{-4}V does not give a central NMR value in line with the expected exponential, although it is comparable within uncertainty, while 1.75×10^{-4}V give a perfectly compatible signal. If the change occurred during run 189859117-2, then the effective value of the $\lambda/2$ resonance amplitude for run 189859117-2 can be any value between 2.72×10^{-4}V and 1.75×10^{-4}V. We added a systematic error to cover

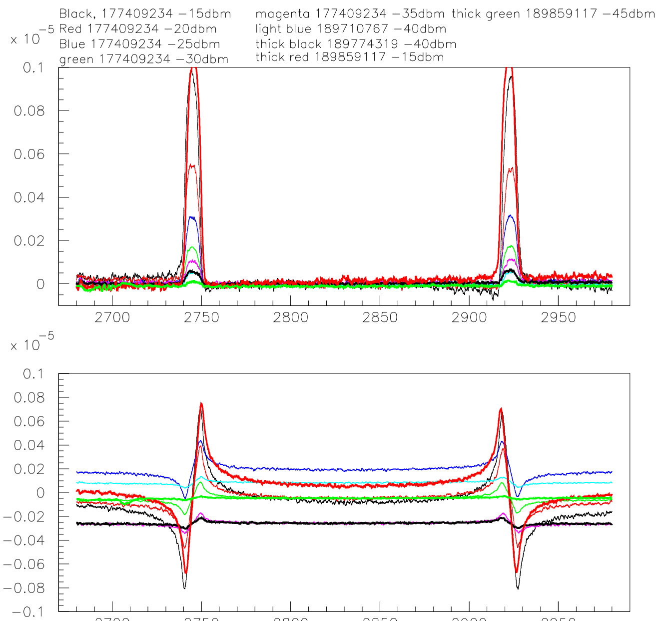


Figure 10:
Variation with RF power of the NMR peak areas. The slight difference of PD temperature has been corrected for but not the difference for $\lambda/2$ resonance amplitude changes.

this uncertainty. Nevertheless, the dominant uncertainty remains statistical. The central value for run 189859117-2 was arbitrarily chosen to be 1.75×10^{-4}V.

After correcting for the $\lambda/2$ resonance amplitude. The signal follows a pure exponential. On Fig. 12, the signals were fitted with the exponential form $48.5 \times 10^{(x/20)}$ where x is the RF power in dBm. The ratios between the measurements and the fit are shown on the bottom of the figure.

7 Analysis of run PD190200064 (H run without exchange gas)

7.1 Run details

The run was done on a HD cell condensed on July 12$^{\text{th}}$ 2011 with relatively high impurity HD gas. Presumably, it has a very small T_1. The characteristics of the circuit $\lambda/2$ resonance appear to have been stable throughout the entire run. The constant parameters for run PD190200064 are given in section 2. The changing parameters and the NMR signal strength (integrated over 30 Gauss) are:

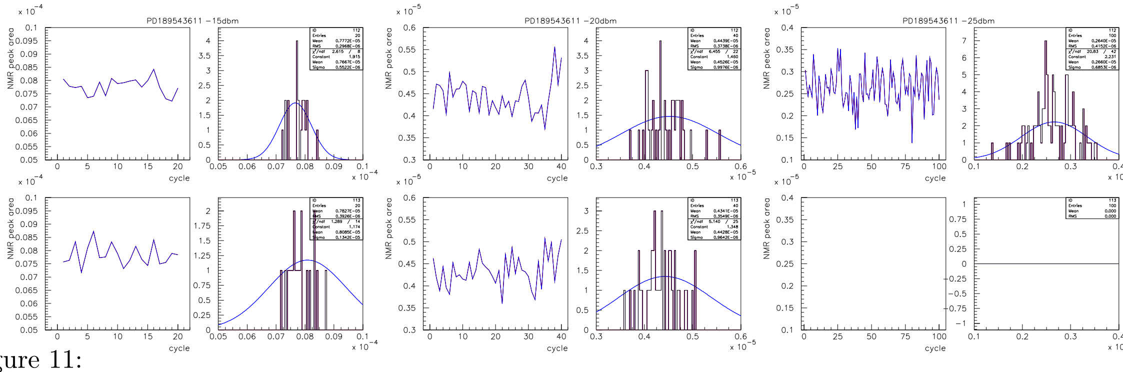
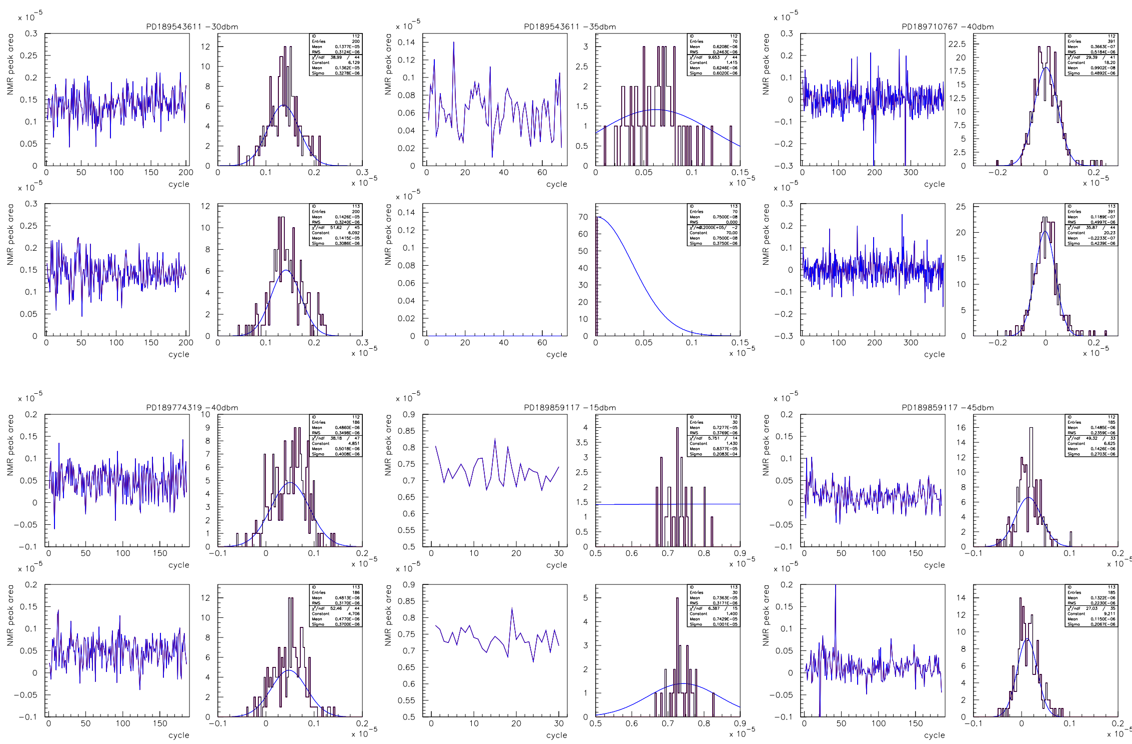


Figure 11:



Peak area jitter. Each panel corresponds to a different RF power. On the left of one panel: Area of the NMR peak vs sweep number (cycle) for the NMR peak for the sweeps done for H. The top plot is for the down sweeps and the bottom plot is for the up sweeps. On the right of one panel: corresponding distributions together with their Gaussian fits. The RMS of the distribution (jitter) is taken as the uncertainty on the measurement.

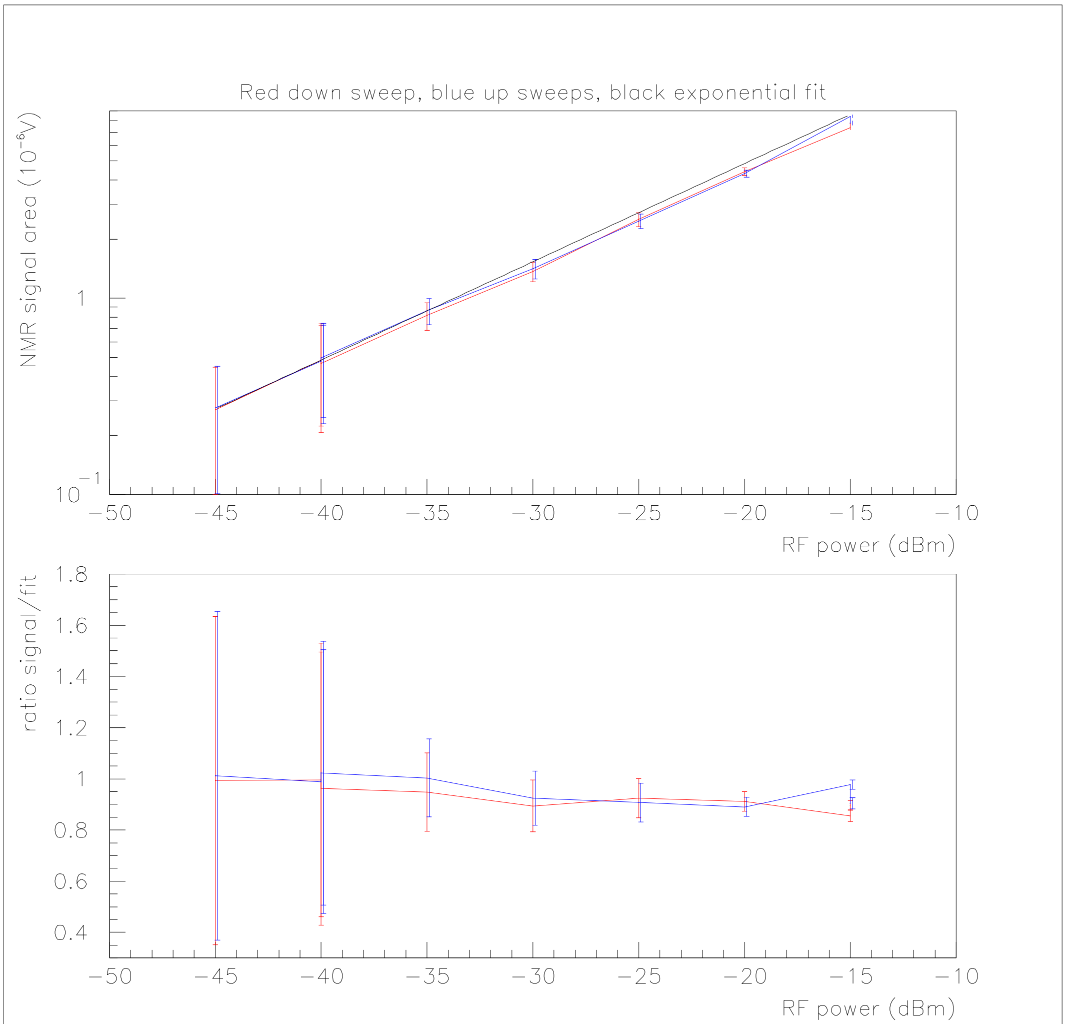


Figure 12:
Top: The red (blue) line gives the dependence of the down (up) NMR signal area in function of RF power. Bottom: ratio of the measured area over the exponential fit in function of the RF power.

run-index	RF power	cycles	area(down/up)×10^6	PD T^o	RF $\lambda/2$ res. amp	Notes
190200064-1	-10dBm	30	8.374/8.267	4.797	2.101×10^{-4}V	Normalization run. RF $\lambda/2$ res. amp measured just before starting the run
190200064-2	-5dBm	30	14.727/14.795	4.797	Same as above	
190200064-3	-10dBm	30	8.293/8.280	4.799	Same as above	Normalization run
190200064-4	-7dBm	50	11.701/11.717	4.800	Same as above	
190200064-5	-10dBm	80	8.361/8.321	4.790	Same as above	
190200064-6	-12dBm	100	6.624/6.524	4.790	Same as above	
190200064-7	-10dBm	30	8.354/8.283	4.790	Same as above	Normalization run
190200064-8	-15dBm	130	4.630/4.637	4.799	Same as above	
190200064-9	-10dBm	30	8.369/8.308	4.779	Same as above	Normalization run
190200064-10	-17dBm	160	3.644/3.629	4.786	Same as above	
190200064-11	-10dBm	30	8.132/8.263	4.794	Same as above	Normalization run
190200064-12	-20dBm	200	2.576/2.580	4.783	Same as above	
190200064-13	-10dBm	6	8.187/8.208	4.786	2.085×10^{-4}V	Normalization run. RF $\lambda/2$ res. amp measured just after finishing the run

The areas in the tables are not corrected yet for the PD temperature difference. The NMR peaks averaged over all sweeps are shown for different RF powers in Fig. 13. The reason why the peaks from the last run are offset is not know. The only particularity is that the run was terminated before the completion of all the cycles. This could explain it if somehow, the final data file (average.dat) is truncated at the completion of the Labview VI. However, we do not believe that it is the case since the file is about the same size as the files from the other run-indices. The only other explanation is that the B-field sweep parameters have changed for this run, for unknown reasons. The NMR frequency appears to have not changed when comparing the circuit $\lambda/2$ resonance done before and after the runs.

7.2 Time dependence of the signals and uncertainty.

We checked the time dependence for the runs. Except possibly for the -5dBm run, there is no visible time dependence of the peak areas, see Fig. 14. This was expected due to the short T_1 of the cell. The jitter of the signal is taken as the uncertainty on the measurement. The means of the distribution correspond to the average signal area given in the table of the previous section.

7.3 NMR signal strength versus RF power

The dependence of the NMR signal area in function of RF power is shown on Fig. 15. The signal follow a pure exponential. On Fig. 15, the signals were fitted with the exponential form $25.8 \times 10^{(x/20)}$ where x is the RF power in dBm. The ratios between the measurements and the fit are shown on the bottom of the figure.

8 Runs with polarized HD targets #19 (Sept 08)

8.1 Run details

The runs were done on the HD cell 19, polarized to about 5.5% (H) and 3.5% (D). Its T_1 is about 20 days (H) and 30 days (D) at about 3K and 2T. The target being in frozen spin mode rather than TE, the PD temperature is irrelevant for this particular study. The $\lambda/2$ resonance was measured at -40 dBm rather than the usual -15dBm, hence the lower value of its amplitude. The PD contained no exchange gas. The constant parameters for the runs are given in section 2. The changing parameters and the NMR signal strength (integrated over 25 Gauss) are:

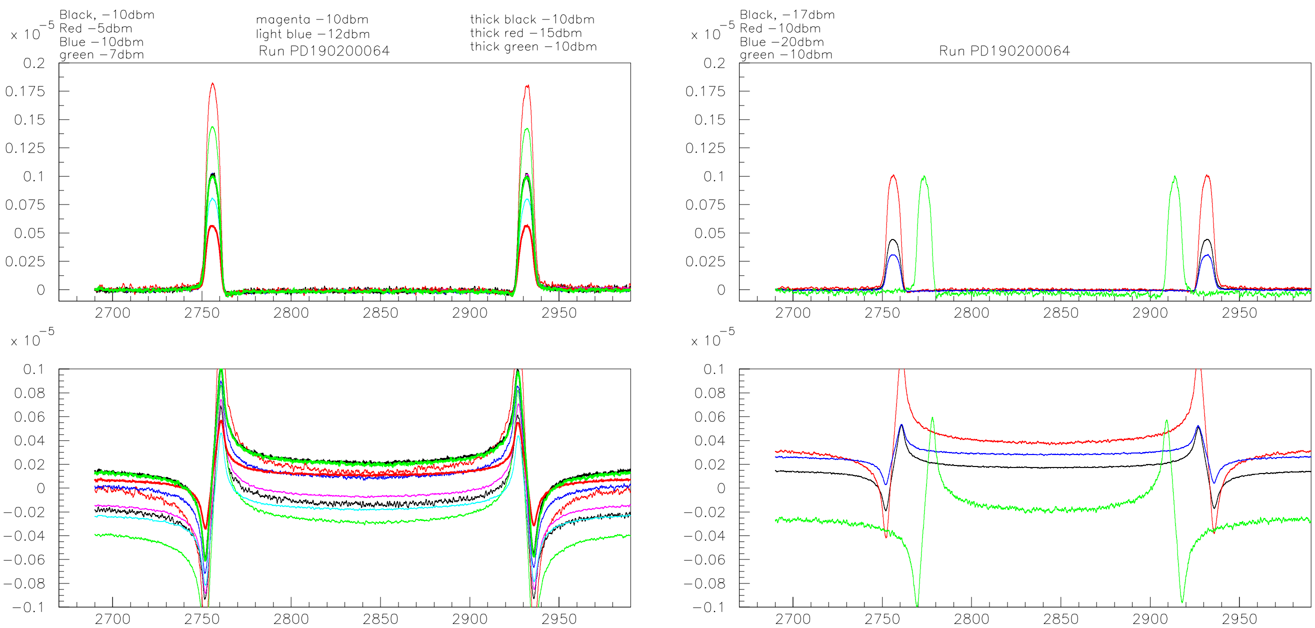


Figure 13:
Variation with RF power of the NMR peak areas. The slight difference of PD temperature has been corrected for. The reason why the peaks from the last run0index are offset is not known.

run-index	RF power	cycles	area(down/up)×10^6	RF $\lambda/2$ res. amp	Notes
191942328	-40dBm	3	77.373/77.0697	1.293×10^{-5}V	
191943060-1	-50dBm	1	24.795/24.738	1.291×10^{-5}V	
191943060-2	-55dBm	1	13.992/13.437	same as above	
PD191943528-1	-35dBm	1	135.989/136.868	same as above	
PD191943528-2	-30dBm	1	245.483/244.262	same as above	
PD191943528-3	-25dBm	1	427.863/425.972	same as above	
PD191943528-4	-60dBm	1	7.894/7.650	same as above	RF $\lambda/2$ res. amp after this run: 1.295×10^{-5}V

Because we took only one or three sweeps, we cannot check the time dependence of the signals. For this reason and due to the large value of the signals, we did not estimate their (statistical) uncertainties.

8.2 NMR signal strength versus RF power

The dependence of the NMR signal area in function of RF power is shown on Fig. 15. The signal follows a pure exponential. On Fig. 15, the signals were fitted with the exponential form $77 \times 10^{(x/20)}$ where x is the RF power in dBm. The ratios between the measurements and the fit are shown on the bottom of the figure.

The signal does not display significant non-linearity in spite of the long T_1 of the target, although the up signal may suggest a slight departure from linearity of a few percent over the -60 to -25 dBm range.

9 Runs with polarized HD targets #19 (Sept 14)

9.1 Run details

The runs were done on the HD cell 19 to check whether the possible non-linearity seen for the up signal in the previous section is real. These data cannot be directly compared to the ones of the previous section due to the decay of the frozen

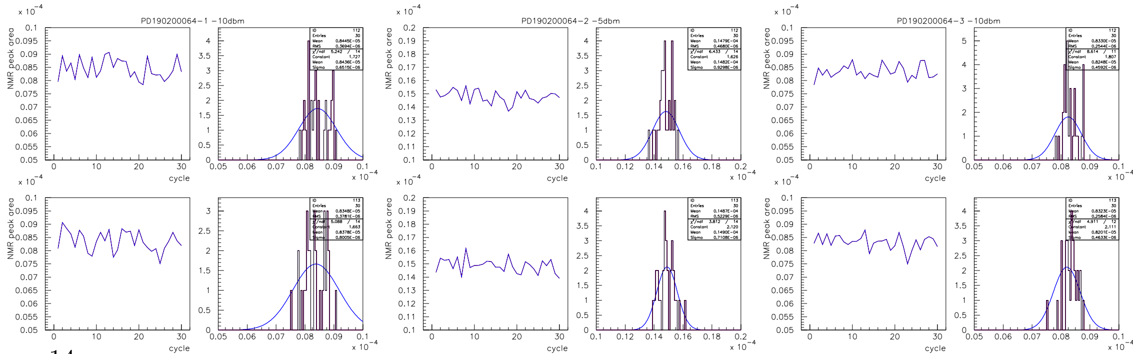
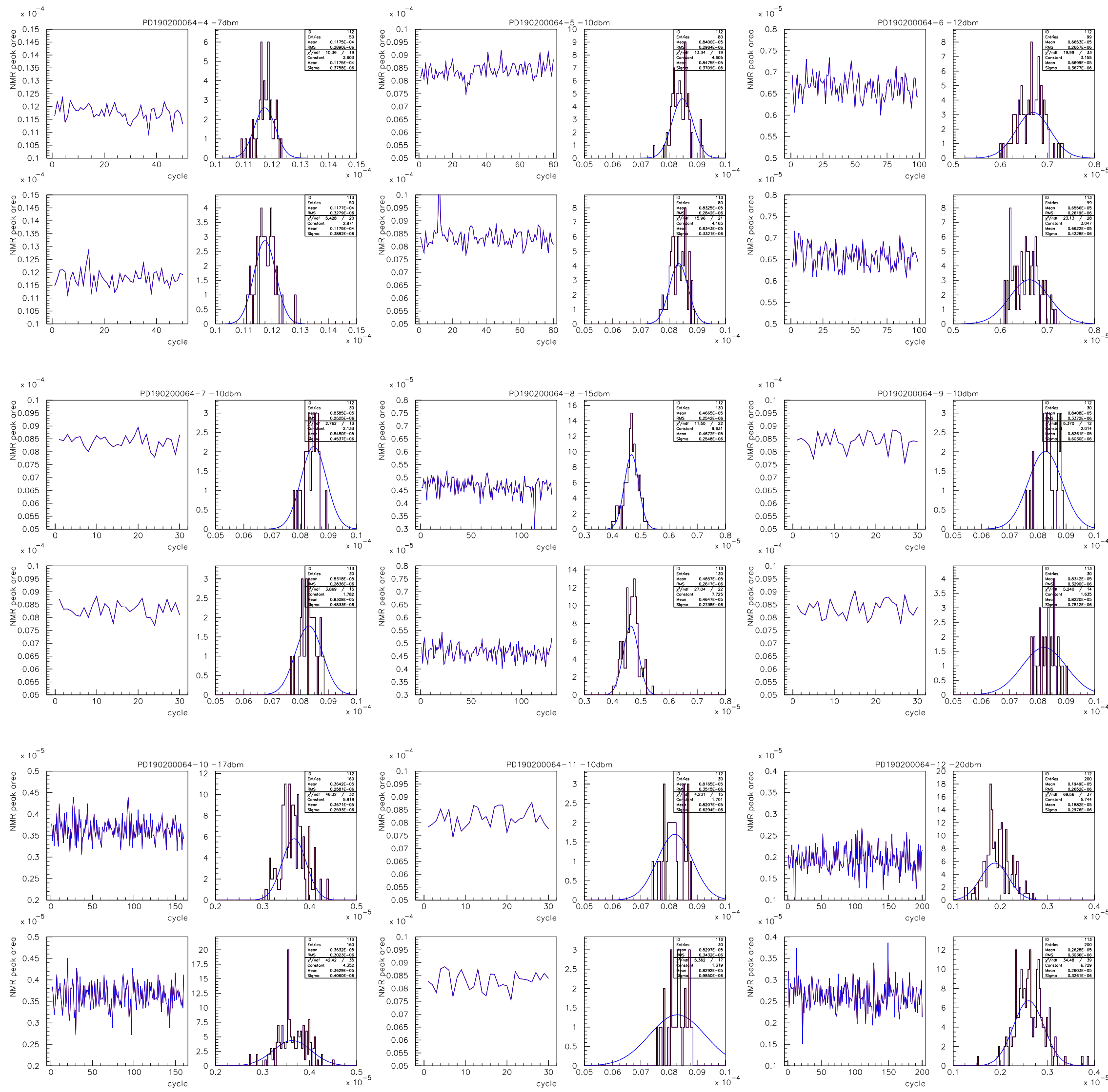
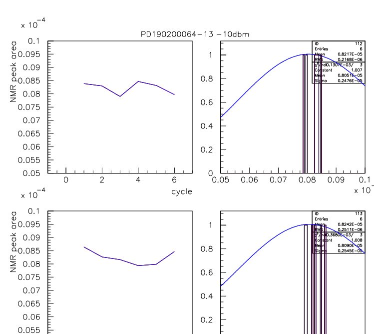
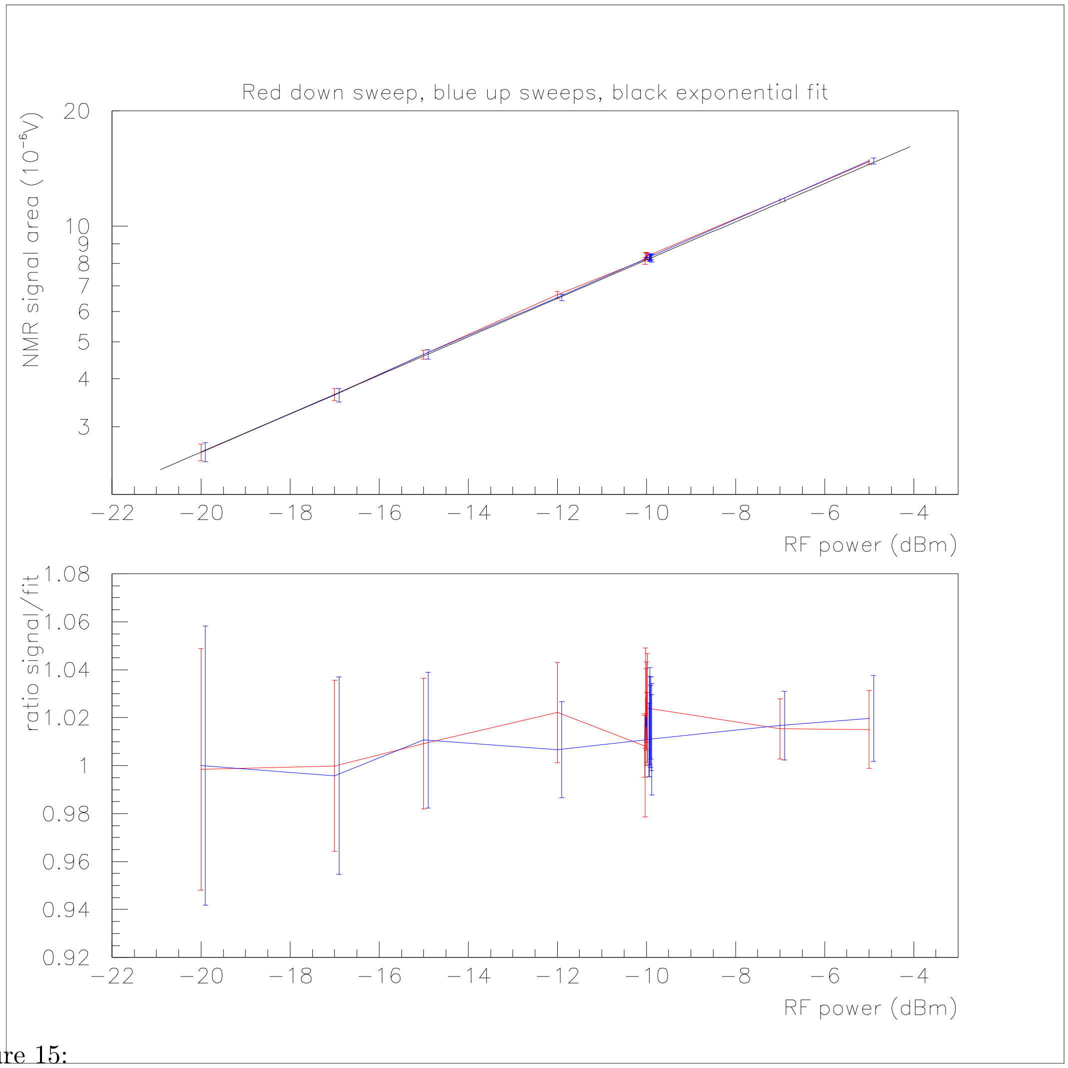

PD190200064-1 -10dbm
PD190200064-2 -5dbm
PD190200064-3 -10dbm
NMR peak area
cycle

Figure 14:


PD190200064-4 -7dbm
PD190200064-5 -10dbm
PD190200064-6 -12dbm
PD190200064-7 -10dbm
PD190200064-8 -15dbm
PD190200064-9 -10dbm
PD190200064-10 -17dbm
PD190200064-11 -10dbm
PD190200064-12 -20dbm
NMR peak area
cycle


PD190200064-13 -10dbm
NMR peak area
cycle



size betwFigure 15:
Top: The red (blue) line gives the dependence of the down (up) NMR signal area in function of RF power. Bottom: ratio of the measured area over the exponential fit in function of the RF power.

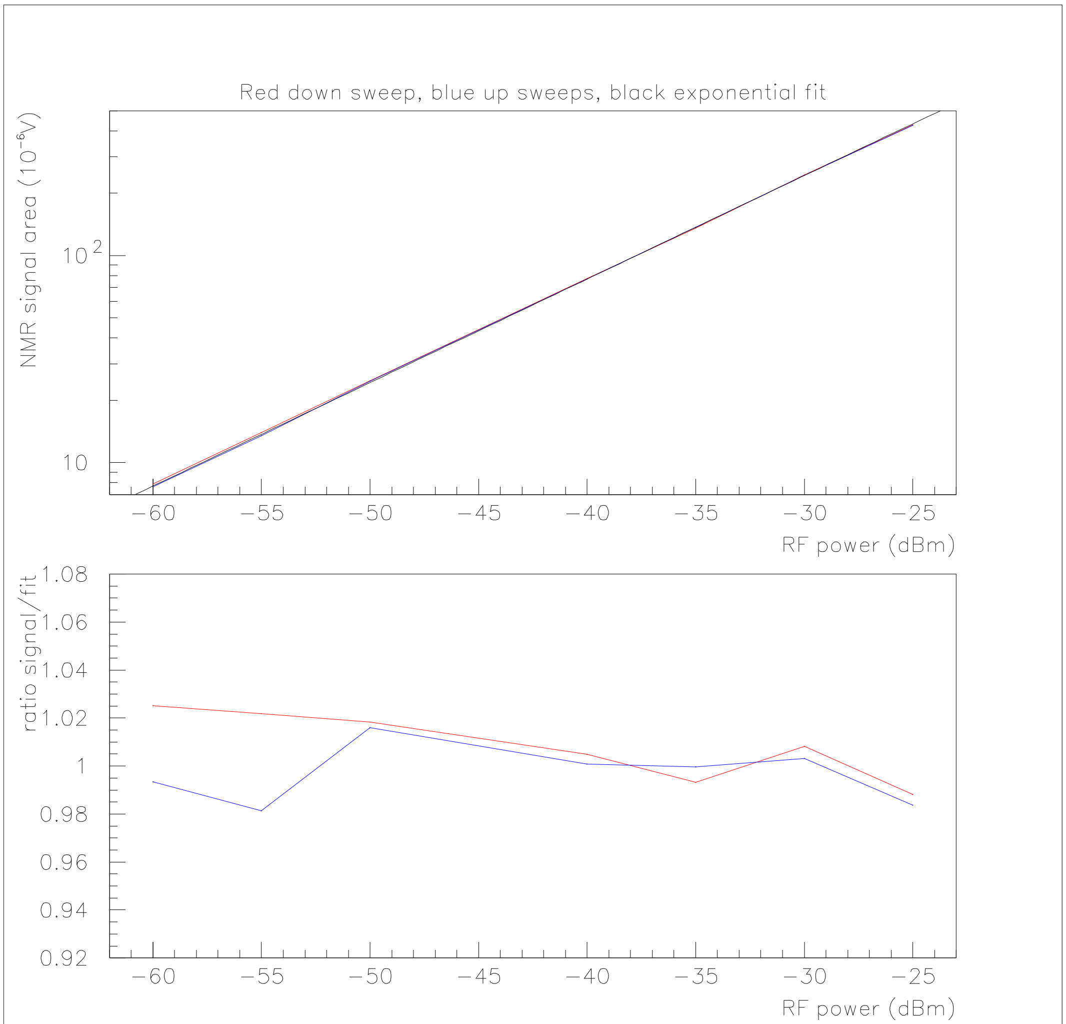


Figure 16:
Top: The red (blue) line gives the dependence of the down (up) NMR signal area in function of RF power. Bottom: ratio of the measured area over the exponential fit in function of the RF power.

spin polarization of target #19. (The data can be nevertheless compared after an overall renormalization.) The target being in frozen spin mode rather than TE, the PD temperature (2.0K) is irrelevant for this particular study. The $\lambda/2$ resonance was measured at -40 dBm rather than the usual -15dBm, hence the lower value of its amplitude. The constant parameters for the runs are given in section 2. The changing parameters and the NMR signal strength (integrated over 25 Gauss) are:

run-index	RF power	cycles	area(down/up)$\times 10^6$	RF $\lambda/2$ res. amp	Notes
192377846-1	-29dBm	2	209.370/208.407	1.295×10^{-5}V	
192377846-2	-32dBm	2	148.162/148.392	1.295×10^{-5}V	
192377846-3	-38dBm	2	74.923/73.114	1.295×10^{-5}V	
192377846-4	-42dBm	3	46.218/46.957	1.295×10^{-5}V	
192377846-5	-45dBm	3	33.307/33.308	1.295×10^{-5}V	
192377846-6	-52dBm	3	14.939/14.917	1.295×10^{-5}V	
192380580-1	-58dBm	4	7.590/7.551	1.295×10^{-5}V	
192380580-2	-40dBm	3	58.253/57.753	1.295×10^{-5}V	

Because we took only three or four sweeps, we cannot check well the time dependence of the signals. For this reason and due to the large value of the signals, we did not estimate their (statistical) uncertainties.

9.2 NMR signal strength versus RF power

The dependence of the NMR signal area in function of RF power is shown on Fig. 15. The signal follows a pure exponential. On Fig. 15, the signals were fitted with the exponential form $59.5 \times 10^{(x/20)}$ where x is the RF power in dBm. The ratios between the measurements and the fit are shown on the bottom of the figure.

The measurement seems to comfirm the slight departure from linearity of a few percent over the -60 to -25 dBm range.

10 Conclusions

Putting all results together, after correcting for temperature and the circuit $\lambda/2$ resonance amplitude, we get:

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In conclusion, the PD NMR system, when used with targets with small T_1 displays an excellent linearity, with its dependence in agreement with the expectation. This was verified with and without exchange gas in the PD. A target with 8.1 min T_1 starts to show non-linearity around -12 dBm, with about 15% deviation from the expected signal at maximum power (0 dBm). Those deviation are due to RF losses that are not recovered fast enough between NMR sweeps. Hence, the deviation depends on the RF power, the time parameters for the sweep ($T_{up,down}$, T_{wait}) and the value of T_1. Measurements with target #19 indicate a departure from linearity of a few percent over the -60 to -25 dBm range. This is presumably due to RF losses (not recovered because of the target is in frozen spin mode). Hence the loss depends both on the number of sweeps and the RF power.

The linearity was verified over wide ranges: for power values between 0 and -60 dBm and signal areas from 0.15 to 430 μV.Gauss

References

[1] A. Deur, HDice_TN11: A. Deur, Systematic study of the NMR sweep parameters.

[2] A. Deur. HDice_TN15; T1 study of the CH2 reference cells.

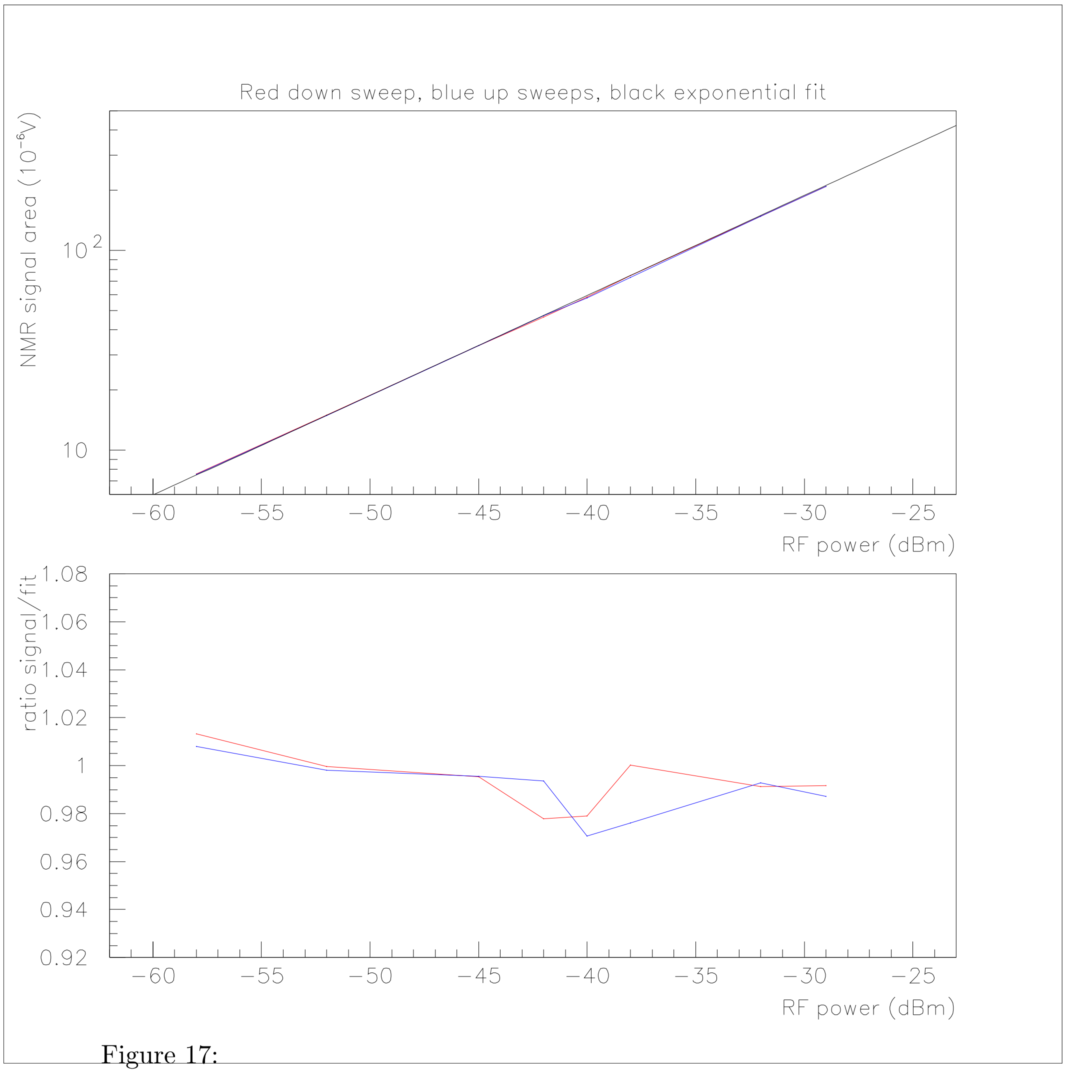

Figure 17:
Top: The red (blue) line gives the dependence of the down (up) NMR signal area in function of RF power. Bottom: ratio of the measured area over the exponential fit in function of the RF power.